Coma Cluster of Galaxies

National Science Education Standards

- Content Standard in 9-12 Science as Inquiry (Abilities necessary to do scientific inquiry, Understanding about scientific inquiry)
- Content Standard in 9-12 Earth and Space Science (Origin and evolution of the universe)

Invisible Cluster

If you aim a big telescope at the Coma Cluster, you'll see galaxies galore — thousands of galaxies of all sizes and shapes, from little puffballs to big, fuzzy footballs. Even so, you won't see most of the cluster because it's invisible to human eyes.

Some of the cluster's "dark side" is in the form of superhot gas that glows in X-rays. All together, the gas is several times as massive as the galaxies themselves.

There's a dynamic interplay between the hot gas and the galaxies.

As galaxies "fall" toward the center of the cluster, they fly through the hot gas, which strips away the cold gas inside the galaxies. Without their cold gas, the galaxies can't give birth to new stars. That helps transform the appearance of some of the galaxies. Spiral galaxies lose their spiral arms, so they look like featureless disks.

But the galaxies may have an effect on the hot gas, too. Over the eons, it should have cooled, but it hasn't. Hot "jets" of particles from the centers of some galaxies may act like big blowtorches, keeping the gas hot.

Yet even the gas and the galaxies combined make up only a small fraction of the Coma Cluster. As much as 80 percent of its mass may consist of dark matter — a form of matter that produces no detectable energy, but that exerts a gravitational pull on the visible matter around it. The dark matter ensures that most of this impressive cluster remains invisible.

This is the transcript of a StarDate radio episode that aired May 6, 2008. Script by Damond Benningfield, ©2008.

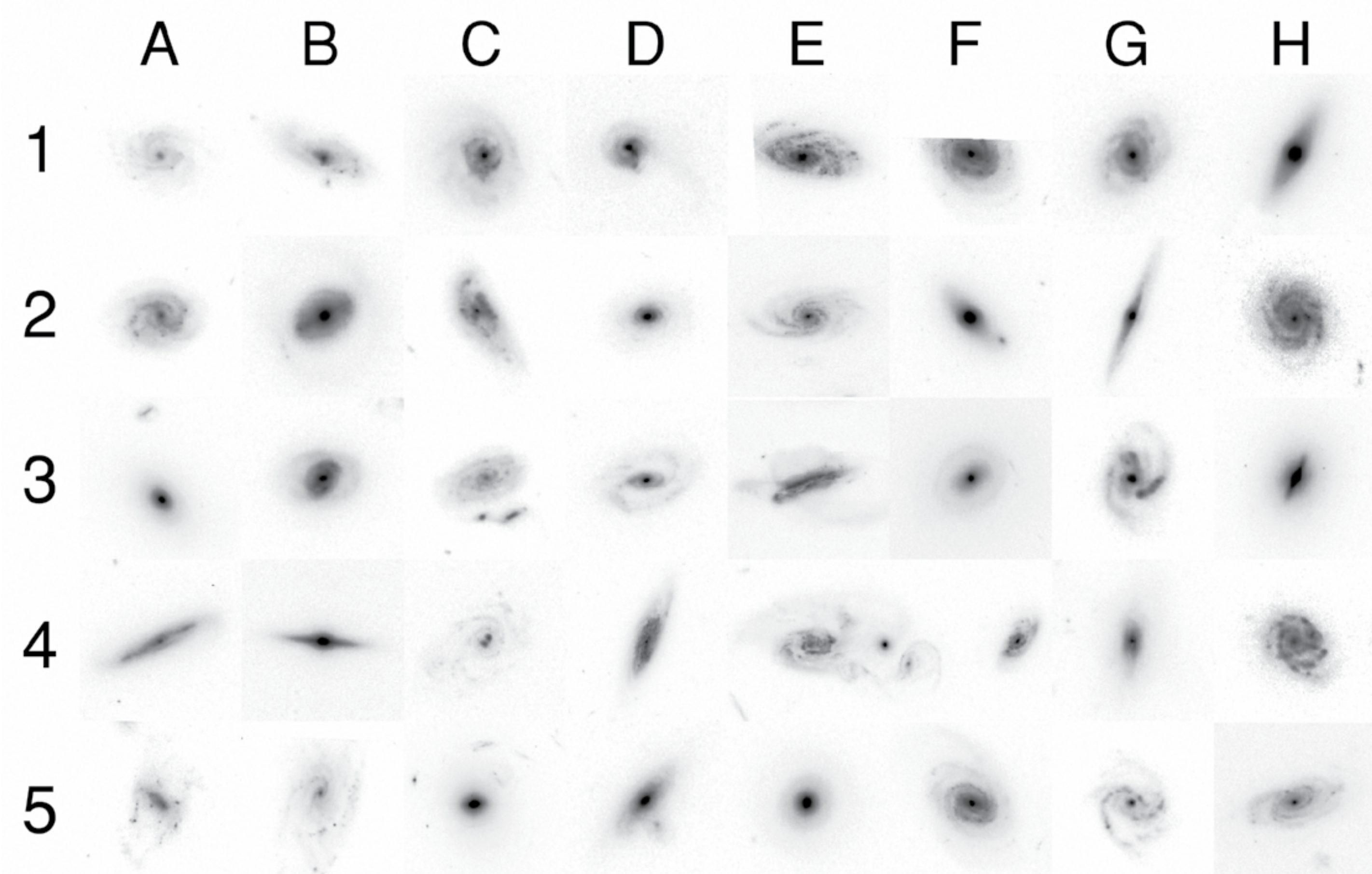
In 2006, Hubble Space Telescope aimed at a nearby collection of galaxies called the Coma Cluster. Using the HST images, astronomers gained fascinating insights into the evolution of galaxies in dense galactic neighborhoods. In this activity, students will first learn the basics of galaxy classification and grouping, then use HST images to discover the "morphology-density effect" and make hypotheses about its causes.

Materials & Preparation

- Each student needs a copy of the next 7 pages (not this page). You may copy the pages out of this guide, but it is recommended that you go to mcdonaldobservatory.org/teachers/classroom and download the student worksheets. The galaxy images in the online worksheets are "negatives" of the real images, which provides better detail when printing. Supplemental materials for this activity are also available on the website.
- Each student or student team will need a calculator and a magnifying glass (a linen tester works well).
- Knowledge of percentages is needed before doing this activity.

Suggested Grading

- **Page 31 (5 pts):** Student provides clear explanations of the scheme.
- **Page 32 (2 pts total, 2 pts each):** Answers: (E/S0/SB0 – 2,6,9), (S – 1,8,12), (SB – 3,4,10), (IR – 5,7,11)
- **Pages 34 and 35:** Not graded; based on student's subjective interpretation.
- **Page 36 (30 pts):** Graded for completion, not accuracy. Students will get different numbers, but math should be correct. Answers for percentages are typically in the following range: (Cluster: E 50 percent, L 30 percent, S 20 percent) (Field: E 20 percent, L 10 percent, S 70 percent). Students usually find a higher percentage of spirals in the field.
- **Page 37 (bottom, 30 pts):** Student hypothesis should mention the effects of interactions and ram-pressure stripping in changing past gas-rich spirals into current gas-poor ellipticals and lenticulars in clusters.



GEMS COLLABORATION

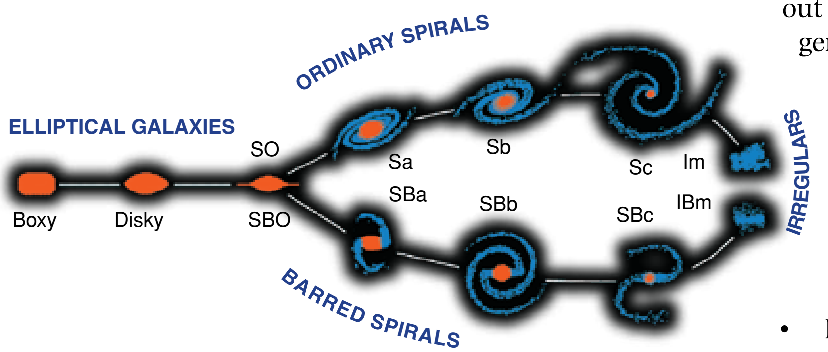
Engage

The diagram above shows a mosaic of 40 galaxies. These images were taken with Hubble Space Telescope and show the variety of shapes that galaxies can assume. When astronomer Edwin Hubble first started studying these various types of galaxies in the 1920s, he realized he needed to develop a way to organize and categorize them. He created a classification scheme in which he grouped similar galaxies together. Your job is to do the same thing. In the chart, invent your own four galaxy types and provide a description and three examples for each one.

Galaxy Type (name and draw)	Defining Characteristics (write a short description, provide enough detail so that anyone could use your scheme)	Three Examples (give 3 grid coordinates)

Explore

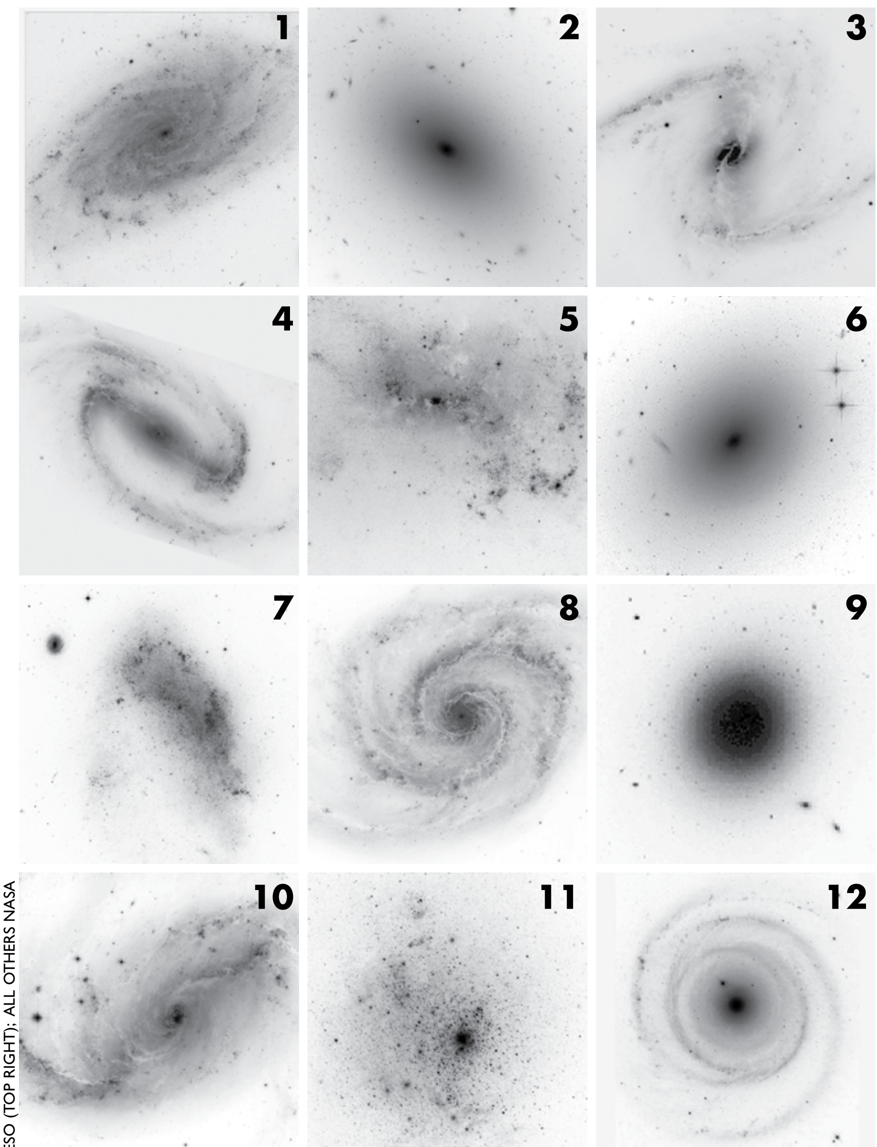
The image on the left is the classification scheme that Hubble himself came up with. He thought that the "tuning fork" sequence represented the evolutionary progression of galaxies. This concept turned out to be wrong, although astronomers still use these general categories and labels to describe galaxies.



JOHN KORMENDY/TIM JONES

The Main Galaxy Types

- **Elliptical (E):** Spherical or elliptical shape (like a football), has no flat disc or spiral arms
- **Lenticular (S0):** Smooth, flat disk shape without spiral structure, often hard to distinguish from ellipticals
- **Barred Lenticular (SB0):** Same as above, but with an elongated (barred) nucleus
- **Spiral (S):** Flat disk shape with notable spiral patterns in the outer disk, also contains a large bright central bulge
- **Barred Spiral (SB):** A special type of spiral characterized by an elongated nucleus with the spiral arms springing from the ends of the bar



ESO (TOP RIGHT); ALL OTHERS NASA

There are two other categories for classifying galaxies:

- **Irregular (IR):** An oddly shaped galaxy that doesn't fit into any other category
- **Interacting (INT):** Two or more galaxies that are so close together that they are affecting each other's shape

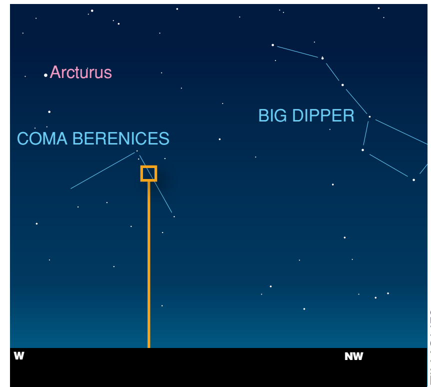
Using the definitions above, place the 12 galaxies on the left into their proper morphology categories:

Morphology	Picture Numbers (3 each)
E/S0/SB0	
S	
SB	
IR	

The smallest galaxies are often called dwarf galaxies (No. 5 and No. 7 are dwarf galaxies). These contain only a few billion stars — a small number compared to the Milky Way's 200 billion. The largest ellipticals contain several trillion stars.

The Coma Galaxy Cluster

The Coma Cluster, which is centered about 320 million light-years away, contains several thousand individual galaxies. The cluster has a roughly spherical shape and is about 20 million light-years across. (For comparison, the Milky Way is 100,000 light-years across). That many galaxies in a relatively small space makes the Coma Cluster one of the richest and densest galaxy clusters in our region of the universe.



TIM JONES

On the following pages you will be asked to count different types of galaxies. Use the labels on this picture as an example of how to count the various objects.

I) Ellipticals or Lenticulars

It can be hard to tell these apart. If you know it's either an E or S0/SB0, it is okay to guess between these two.

II) Spirals and Barred Spirals

It can be hard to tell these apart. If you know it's either an S or SB, it is okay to guess between these two.

III) Irregular galaxy

IV) Uncertain

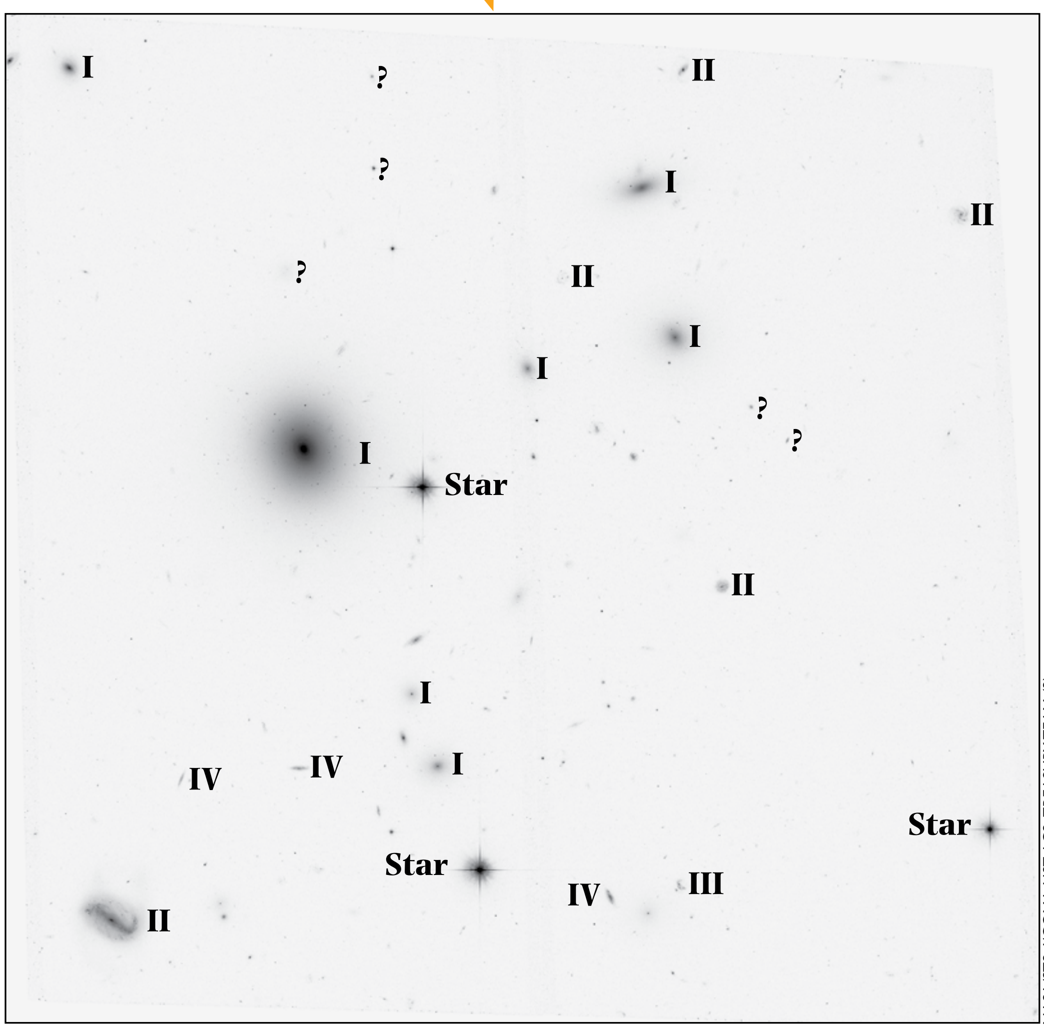
An edge-on view of a galaxy that could possibly be an S0, SB0, S, SB, or IR. There are too many possibilities, so do not count these.

Star)

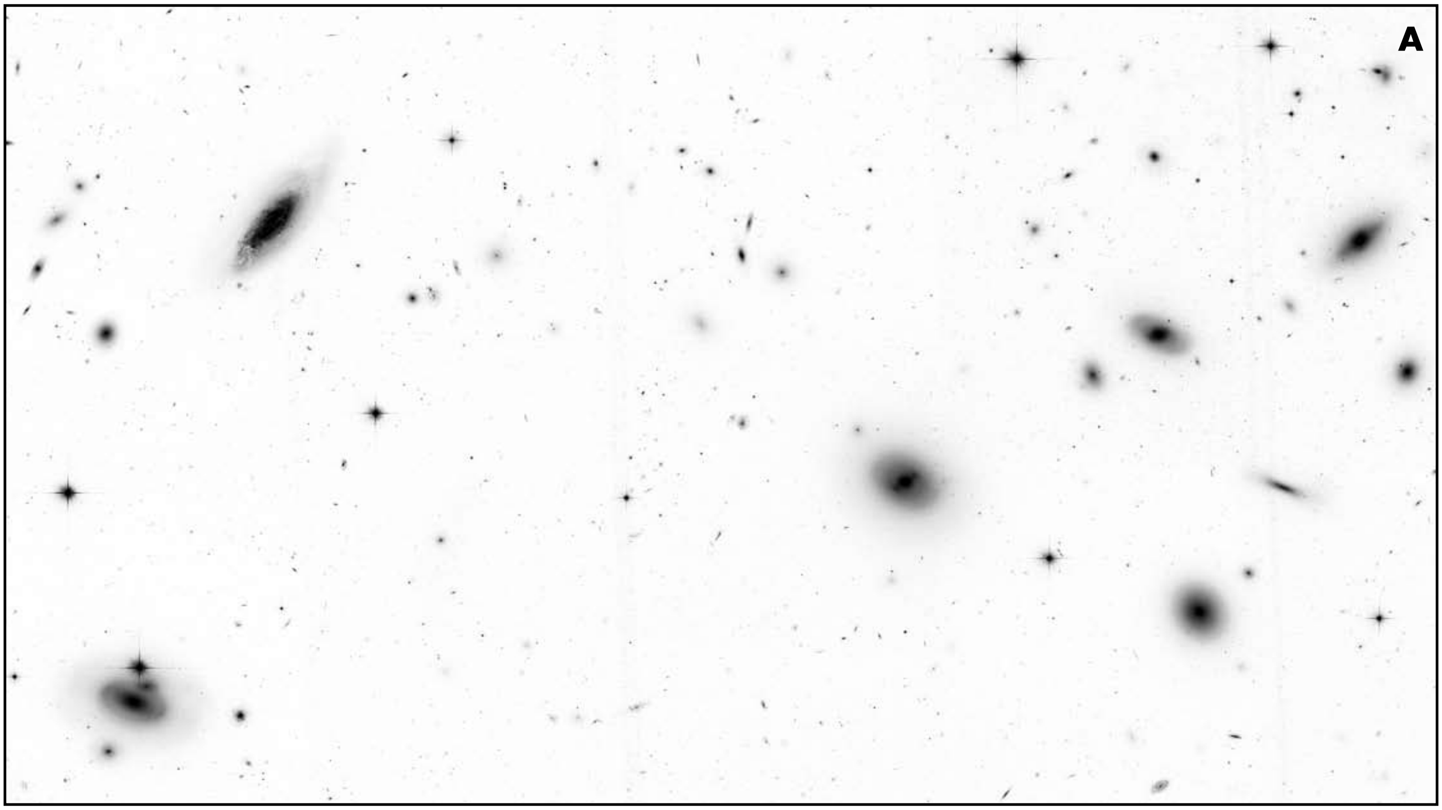
Any object that has "crosshairs" sticking out of it is a foreground star in the Milky Way galaxy, so do not count these.

?)

Don't count small, faint objects like these that are too hard to classify.

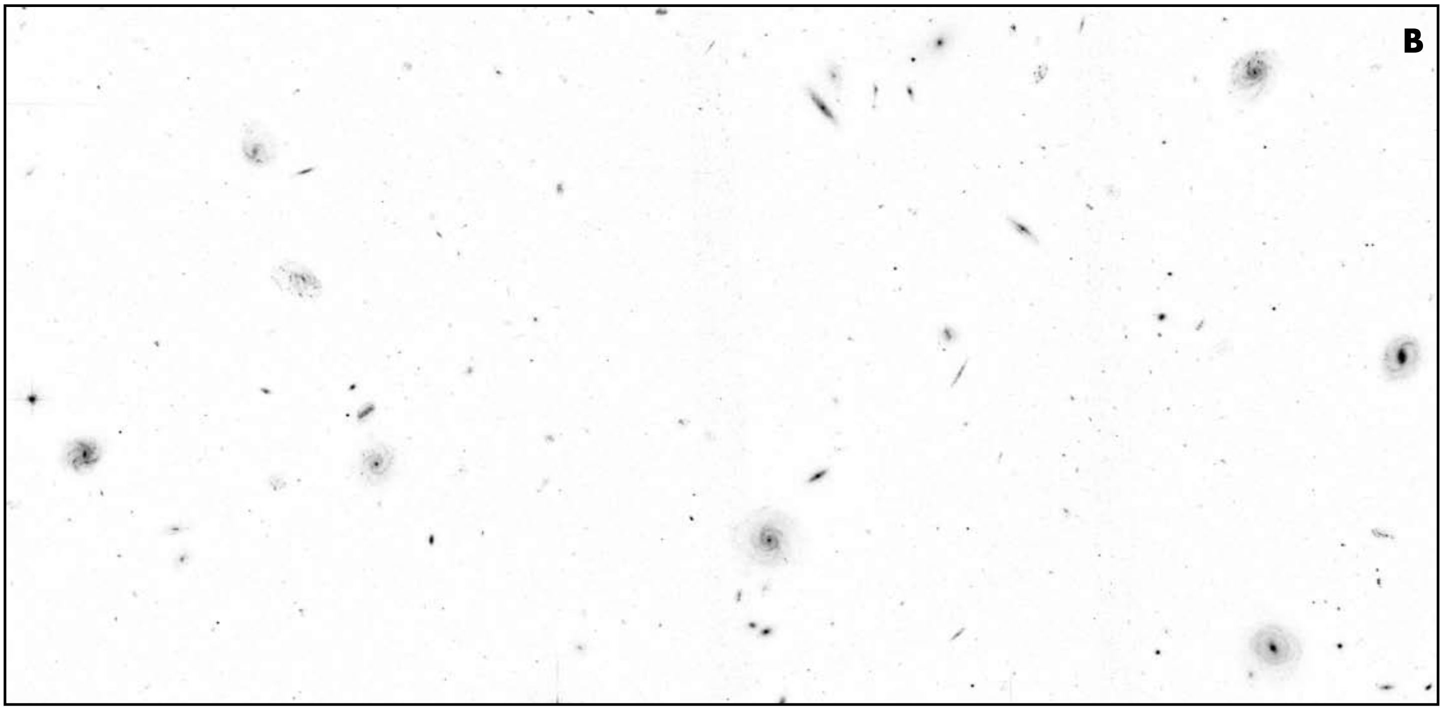


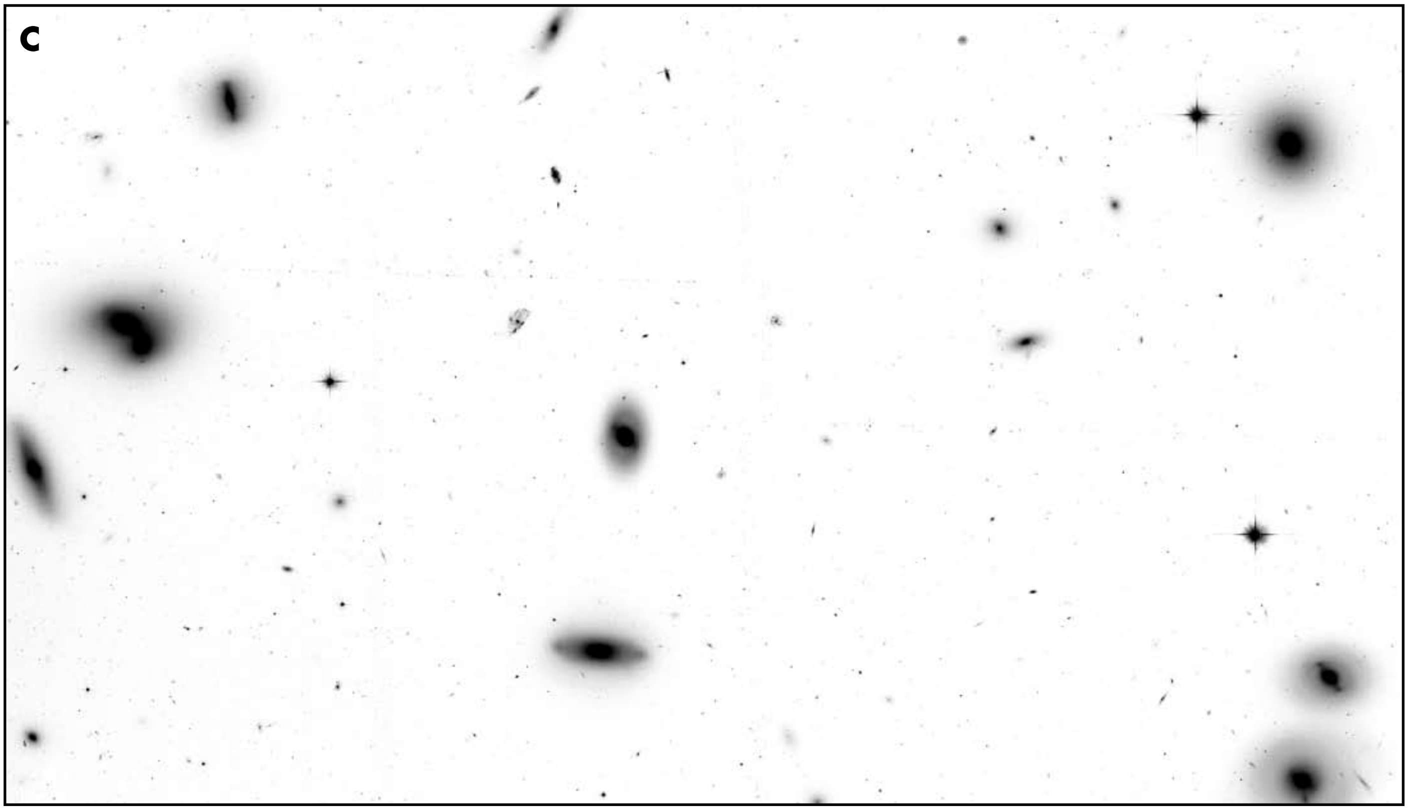
NASA/STScI/COMA HST ACS TREASURY TEAM (3)



Count the number of galaxies of each morphological type and write down the number in the correct spot in the table. Use the guidelines on page 4 to help you decide which objects to count.

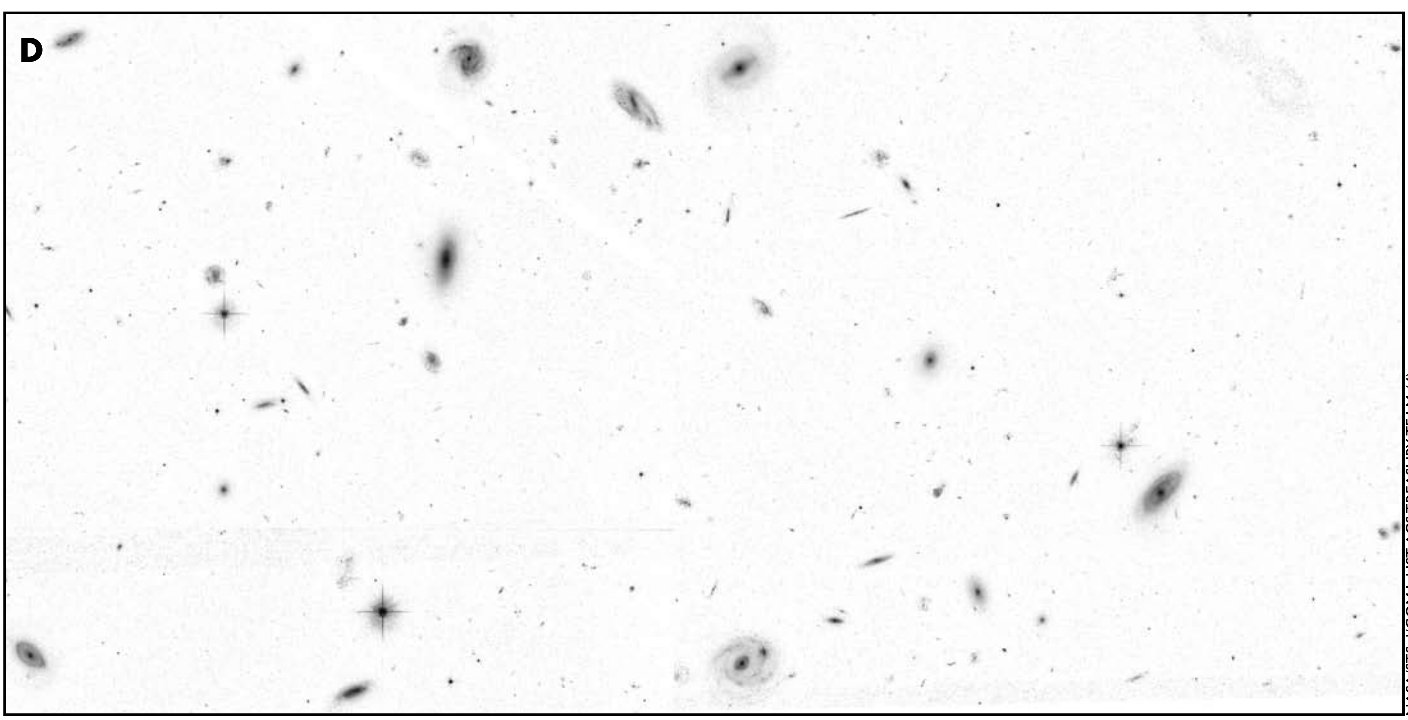
	E	S0 /SB0	S	SB	IR / INT
Top Image (A)					
Bottom Image (B)					





	E	S0 /SB0	S	SB	IR / INT
Top Image (C)					
Bottom Image (D)					

Count the number of galaxies of each morphological type and write down the number in the correct spot in the table. Use the guidelines on page 4 to help you decide which objects to count.



NASA/STScI/COMA HST ACS TREASURY TEAM (4)

Explain

Galaxies in Clusters, Groups, and the Field

Galaxies are found throughout the universe, from our next door neighbors — the Magellanic Clouds and Andromeda — all the way out to the edge of the visible universe 13 billion light years away. Nobody knows for sure, but it is estimated that there are 100 billion galaxies or more in the visible universe, and many more beyond that. Galaxies live in a variety of environments. Sometimes large numbers of them are packed close together in clusters, such as the Coma Cluster; sometimes they gather in smaller numbers called groups, like the Local Group that contains our Milky Way; and sometimes they are isolated far from one another in the field.

	Number of Galaxies	Minimum Number of Non-dwarf Galaxies	Diameter (1 Mpc 3.26 million light years)	Total Mass
Galaxy Cluster Large and dense	50 to thousands	6	2 to 10 Mpc	10^{14} to 10^{15} solar masses
Galaxy Group Small and dense	less than 50	3	1 to 2 Mpc	10^{13} solar masses
The Field Large and deserted	very few	0	Voids, can be larger than 100 Mpc	$< 10^{10}$

Clusters, groups, and some isolated galaxies can all be part of even larger structures called superclusters. At the largest scales in the visible universe, superclusters are gathered into filaments and walls surrounding vast voids, often described as resembling large soap bubbles. This structure often is referred to as the "cosmic web."

On the previous two pages, the images on the top (A&C) show the dense central core of the Coma Cluster, and the images on the bottom (B&D) show galaxies out in the field. Fill in the table below using the numbers you wrote down on the previous two pages:

	Morphology→	E Ellipticals	S0 & SB0 Lenticulars	S & SB (sum both together) Regular and Barred Spirals	Total (E+S0+SB0+S+SB)
Coma Cluster	Image A				
	Image C				
	Sum Total From A + C	(e)	(f)	(g)	(h)
The Field	Image B				
	Image D				
	Sum Total From B + D	(i)	(j)	(k)	(m)

Using a calculator, find the percentages of each galaxy type in the cluster versus the field (ignore IRs and INTs). Fill in each of the boxes on the right:

In the Cluster:

% of Ellipticals ($\frac{e}{h}$) = ☐ %

% of Lenticulars ($\frac{f}{h}$) = ☐ %

% of Spirals ($\frac{g}{h}$) = ☐ %

In the ı ld:

% of Ellipticals ($\frac{i}{m}$) = ☐ %

% of Lenticulars ($\frac{j}{m}$) = ☐ %

% of Spirals ($\frac{k}{m}$) = ☐ %

Where did you find a higher percentage of spirals — in the Cluster or in the Field? Answer: ______________________

The percentages that you just found tell us which types of galaxies are common in the Coma Cluster versus which types are common in the field. Astronomers have done this same exercise on hundreds of thousands of galaxies in the nearby universe, and discovered that the following percentages are pretty typical:

- In dense clusters, 40 percent of the galaxies are ellipticals, 50 percent are lenticulars, and 10 percent are spirals.
- In the field, 10 percent of the galaxies are ellipticals, 10 percent are lenticulars, and 80 percent are spirals.

When galaxies are found very close together there are more ellipticals and lenticulars. When galaxies are far apart there are more spirals. Astronomers call this the "morphology-density effect" (the word morphology means "type" or "class," not "transformation," as in biology). The term basically means that in crowded galaxy neighborhoods, like clusters, there are different types of galaxies than are found in open areas, like the field.

Extend

The clues needed to answer the last question are in the following paragraphs. Please read the paragraphs carefully and then answer the question at the right.

As a general rule, spiral galaxies (S and SB) have a lot of gas and are still forming lots of new stars. Elliptical and lenticular galaxies (E, S0, and SB0) are gas poor and are not making many new stars.

Spirals are Gas-rich
Both Ellipticals and Lenticulars are Gas-poor

Galaxies that are very close to each other, such as those in clusters, often undergo many violent interactions with each other. When a gas-rich spiral galaxy interacts with another galaxy, it tends to quickly use up most of its gas to make new stars, leaving little gas behind. Galaxy-galaxy interactions often change gas-rich galaxies into gas-poor galaxies. Many lenticular galaxies are the remains of old spirals that have lost their gas, and many elliptical galaxies are the remains of several spiral galaxies that have collided.

Galaxy clusters are usually filled with a lot of extremely hot gas that is spread between galaxies throughout the cluster. However, there is no hot gas like this out in the field. When the radiation from this hot gas hits a spiral galaxy, it strips the spiral galaxy of its much cooler gas in a process called *ram-pressure stripping*. This process quickly converts a gas-rich spiral galaxy into a gas-poor lenticular galaxy. Spiral galaxies have a hard time surviving in the superheated gas environment.

Using what you've learned, write a hypothesis that might explain why we see the morphology-density effect. In other words, why do we see more elliptical and lenticular galaxies in clusters and more spiral galaxies in the field? Remember that galaxies change and evolve over time, and these galaxies have had a very long time to get to this point.